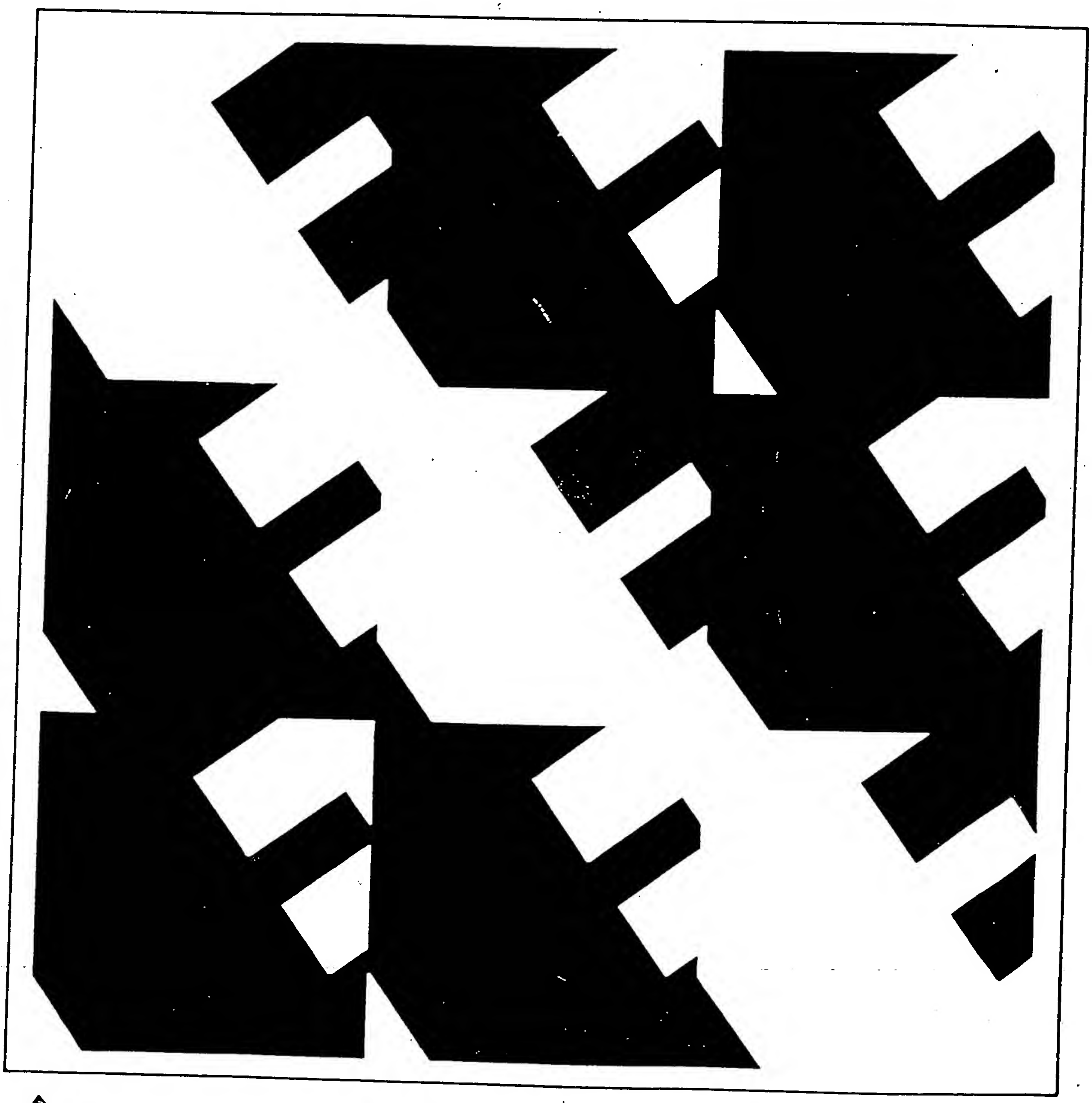
AMERICAN NATIONAL STANDARD

ANSI/IEEE Std 450-1987
(Revision of ANSI/IEEE Std 450-1980)

IEEE Recommended Practice for Maintenance, Testing, and Replacement of Large Lead Storage Batteries for Generating Stations and Substations

ANSI/IEEE Std 450-1987



Published by The Institute of Electrical and Electronics Engineers, Inc 345 East 47th Street, New York, NY 10017, USA
March 9, 1987
SH10991

ANSI/IEEE
Std 450-1987
(Revision of ANSI/IEEE
Std 450-1980)

An American National Standard

IEEE Recommended Practice for Maintenance, Testing, and Replacement of Large Lead Storage Batteries for Generating Stations and Substations

Sponsor

**Power Generation Committee
of the
IEEE Power Engineering Society**

Approved June 19, 1986

IEEE Standards Board

Approved November 17, 1986

American National Standards Institute

Foreword

(This Foreword is not a part of ANSI/IEEE Std 450-1987, IEEE Recommended Practice for Maintenance, Testing, and Replacement of Large Lead Storage Batteries for Generating Stations and Substations.)

Large stationary lead storage batteries play an ever increasing role in substation and generating station control and power systems and in providing the back-up energy for emergencies. This recommended practice fulfills the need within the industry to provide common or standard practices of maintenance, testing, and replacement. The methods described are applicable to all installations and battery sizes.

The installations considered herein are designed for *full-float* operation with a battery charger serving to maintain the battery in a charged condition as well as to supply the normal dc load.

This recommended practice may be used separately, and, when combined with IEEE Std 484-1987, IEEE Recommended Practice for Installation Design and Installation of Large Lead Storage Batteries for Generating Stations and Substations, and ANSI/IEEE Std 485-1983, IEEE Recommended Practice for Sizing Large Lead Storage Batteries for Generating Stations and Substations, will provide the user with a general guide to sizing, designing, placing in service, maintaining, and testing a large storage battery installation. A companion document, ANSI/IEEE Std 535-1986, provides a Standard for Qualification of Class 1E Lead Storage Batteries for Nuclear Power Generating Stations. As a recommended practice, this document presents procedures and positions preferred by the IEEE.

The IEEE will maintain this recommended practice current with the state of the technology. Comments on this recommended practice and suggestions for additional material that should be included are invited. These should be addressed to:

Secretary
IEEE Standards Board
The Institute of Electrical and Electronics Engineers, Inc
345 East 47th Street
New York, NY 10017

This recommended practice was prepared by the working group on Batteries, Station Design Subcommittee of the Power Generation Committee of the IEEE Power Engineering Society. At the time this recommended practice was approved, the members of the working group were:

J. H. Bellack, *Chairman*

M. Balanson	D. O. Feder	J. Montalbano
D. L. Basdekas	K. Floyd	B. Radimer
W. Bates	J. Goudier	H. K. Reid
L. F. Bednar	R. S. Green	T. Ruhlmann
J. L. Chamberlin	R. Hopewell	B. G. Treece
V. E. Dalke	R. Kelleher	G. Tsouderos
E. Daniels	D. S. Levin	P. J. Vivona
P. J. Demar	S. Meissel	G. Walker

The liaison representatives were:

K. L. Sommer, *Substations Committee*
L. C. Gonzalez and P. Kine, *Nuclear Power Engineering Committee*

The following persons were on the balloting committee that approved this document for submission to the IEEE Standards Board:

W. W. Avril
M. S. Baldwin
J. H. Bellack
I. B. Berezowsky
G. Berman
R. W. Cantrell
H. E. Church
R. S. Coleman
R. E. Cotta
M. L. Crenshaw
D. J. Damsker
P. M. Davidson
G. R. Engmann
W. M. Fenner
A. H. Ferber
D. I. Gorden
R. D. Handel
J. H. Jones
F. W. Keay
P. R. Landrieu
J. T. Madill
O. S. Mazzoni
M. W. Migliaro
J. T. Nikolas
R. E. Penn
J. D. Plaxco
R. J. Reiman
D. E. Roberts
R. G. Scott
A. J. Spurgin
G. I. Stillman
J. E. Stoner, Jr.
J. B. Sullivan
T. R. Whittemore
J. P. Wooley

When the IEEE Standards Board approved this standard on June 19, 1986, it had the following membership:

John E. May, *Chairman*
Irving Kolodny, *Vice Chairman*
Sava I. Sherr, *Secretary*

James H. Beall
Fletcher J. Buckley
Paul G. Cummings
Donald C. Fleckenstein
Jay Forster
Daniel L. Goldberg
Kenneth D. Hendrix
Irvin N. Howell
Jack Kinn
Joseph L. Koepfinger*
Edward Lohse
Lawrence V. McCall
Donald T. Michael*
Marco W. Migliaro
Stanley Owens
John P. Riganati
Frank L. Rose
Robert E. Rountree
Martha Sloan
Oley Wanaselja
J. Richard Weger
William B. Wilkens
Helen M. Wood
Charles J. Wylie
Donald W. Zipse

*Member emeritus

An American National Standard

IEEE Recommended Practice for Maintenance, Testing, and Replacement of Large Lead Storage Batteries for Generating Stations and Substations

1. Scope

This recommended practice is limited to providing recommended practices of maintenance, test schedules, and testing procedures that can be used to optimize the life and performance of large lead storage batteries. It also provides guidance to determine when batteries should be replaced. There are other test procedures and replacement techniques used within the industry (especially for smaller substation batteries) which are equally as effective but are beyond the scope of this recommended practice.

Sizing, installation, qualification, other battery types, and application are also beyond the scope of this recommended practice.

This recommended practice does not include any other component of the dc system nor surveillance and testing of the dc system, even though the battery is part of that system. Preoperational and periodic dc system tests of chargers and other dc components may require that the battery be connected to the system. Details for these tests will depend on the requirements of the dc system and are beyond the scope of this recommended practice.

2. Definitions

The following definitions apply specifically to the subject matter of this recommended practice. For other definitions see Section 3, References.

acceptance test (lead storage batteries). A constant current capacity test made on a new battery to determine that it meets specifications or manufacturer's ratings.

battery rack. A structure used to support a group of cells.

capacity test (lead storage batteries). A discharge of a battery to a designated terminal voltage.

performance test (lead storage batteries). A constant current capacity test made on a battery normally in the "as found" condition, after being in service, to detect any change in the capacity determined by the acceptance test.

service test (lead storage batteries). A special test of the battery's capability, as found, to satisfy the design requirements (battery duty cycle) of the dc system.

terminal connection detail (lead storage batteries). Connections made between rows of cells or at the positive and negative terminals of the battery, which may include lead-plated terminal plates, cables with lead-plated lugs, and lead-plated rigid copper connectors.

3. References

This recommended practice shall be used in conjunction with the following publications:

[1] ANSI/IEEE Std 100-1984, IEEE Standard Dictionary of Electrical and Electronics Terms.[1]

[2] ANSI/IEEE Std 308-1980, IEEE Standard Criteria for Class 1E Power Systems for Nuclear Power Generating Stations.

[3] ANSI/IEEE Std 323-1983, IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations.

[1] ANSI publications are available from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY, 10018.

[4] ANSI/IEEE Std 485-1983, IEEE Recommended Practice for Sizing Large Lead Storage Batteries for Generating Stations and Substations.

[5] ANSI/IEEE Std 494-1974 (R1983), IEEE Standard Method for Identification of Documents Related to Class 1E Equipment and Systems for Nuclear Power Generating Stations.

[6] ANSI/IEEE Std 535-1986, IEEE Standard for Qualification of Class 1E Lead Storage Batteries for Nuclear Power Generating Stations.

[7] ANSI/IEEE Std 946-1985, IEEE Recommended Practice for the Design of Safety Related DC Auxiliary Power Systems for Nuclear Power Generating Stations.

[8] IEEE Std 484-1987, IEEE Recommended Practice for Installation Design and Installation of Large Lead Storage Batteries for Generating Stations and Substations.[2]

4. Maintenance

4.1 General. Proper maintenance will prolong the life of a battery and will aid in assuring that it is capable of satisfying its design requirements. A good battery maintenance program will serve as a valuable aid in determining the need for battery replacement. Station battery maintenance should be performed by personnel knowledgeable of batteries and the safety precautions involved.

4.2 Safety. The safety precautions listed herein should be followed in station battery maintenance. Work performed on batteries should be done only with the proper and safe tools and with the protective equipment listed.

4.2.1 Methods. Work performed on a battery in service should use methods to preclude circuit interruption or arcing in the vicinity of the battery.

4.2.2 Protective Equipment. The following protective equipment should be available to personnel who perform battery maintenance work:

(1) Goggles and face shields
(2) Acid-resistant gloves
(3) Protective aprons
(4) Portable or stationary water facilities for rinsing eyes and skin in case of acid spillage
(5) Bicarbonate of soda, mixed 1 lb to one gal water.

4.2.3 Precautions. The following protective procedures should be observed during maintenance:

(1) Use tools with insulated handles.
(2) Prohibit smoking and open flames, and avoid arcing in the immediate vicinity of the battery.
(3) Ensure that the load test leads are connected with sufficient length of cable to prevent accidental arcing in the vicinity of the battery.
(4) All connections to load test equipment should include short-circuit protection.
(5) Ensure that battery area ventilation is operable.
(6) Ensure unobstructed egress from the battery area.
(7) Avoid the wearing of metallic objects such as jewelry.
(8) Neutralize static buildup just before working on battery by having personnel contact nearest effectively grounded surface.

4.3 Inspections. All inspections should be made under normal float conditions. Specific gravity readings are not meaningful during charge or following the addition of water. Readings should be taken in accordance with the manufacturer's instructions. Refer to the Appendixes for more information.

4.3.1 General. Inspection of the battery on a regularly scheduled basis (at least once per month) should include a check and record of the following:

(1) Float voltage measured at battery terminal
(2) General appearance and cleanliness of the battery, the battery rack, and battery area
(3) Charger output current and voltage
(4) Electrolyte levels
(5) Cracks in cells or leakage of electrolyte
(6) Any evidence of corrosion at terminals, connectors, or racks
(7) Ambient temperature and condition of ventilation equipment
(8) Pilot-cell (if used) voltage, specific gravity, and electrolyte temperature

4.3.2 Quarterly. At least once per quarter a general inspection should be augmented as follows. Check and record:

(1) Specific gravity of each cell
(2) Voltage of each cell and total battery terminal voltage

[2] IEEE publications are available from the IEEE Service Center, 445 Hoes Lane, Piscataway, NJ, 08854.

(3) Temperature of electrolyte in representative cells. (Suggestion: take the temperature in cells number 6, 12, 18, . . .)

4.3.3 Yearly. At least once each year a quarterly inspection should be augmented as follows. Check and record:

(1) Cell condition. (This would involve a detailed visual inspection of each cell in contrast to the general inspection in 4.3.1. Review manufacturer's recommendations.)

(2) Cell-to-cell and terminal connection detail resistance. (See Appendix D2.)

(3) Integrity of the battery rack.

4.3.4 Special Inspections. If the battery has experienced an abnormal condition (such as a severe discharge or overcharge), an inspection should be made to assure that the battery has not been damaged. Include the requirements of 4.3.1 and 4.3.2.

4.4 Corrective Actions

4.4.1 The following items indicate conditions that can be easily corrected prior to the next general inspection.

(1) When any cell electrolyte reaches the low-level line, water should be added to bring all cells to the high-level line. Water quality should be in accordance with manufacturer's instructions.

(2) If resistance readings obtained in 4.3.3 (2) are more than 20% above the installation value or above a ceiling value established by the manufacturer, or if loose connections are noted, retorque and retest. If terminal corrosion is noted or if retested resistance value remains unacceptable, the connection should be disassembled, cleaned, reassembled, and retested. Refer to IEEE Std 484-1987 [8][3] for detailed procedures. Note also Appendix D2.

(3) When cell temperatures deviate more than 3 °C (5 °F) from each other during a single inspection, determine the cause and correct.

(4) When excessive dirt is noted on cells or connectors, wipe with water-moistened clean wiper. Remove electrolyte spillage on cell covers and containers with a bicarbonate of soda solution (1 lb bicarbonate of soda to 1 gal water). Avoid the use of hydrocarbon-type cleaning agents (oil distillates) and strong alkaline cleaning agents, which may cause containers and covers to crack or craze.

(5) When the float voltage, measured at the battery terminals, is outside of its recommended operating range, it should be adjusted.

4.4.2 *The following items indicate conditions that, if allowed to persist for extended periods, can reduce battery life. They do not necessarily indicate a loss of capacity.* Therefore the corrective action can be accomplished prior to the next quarterly inspection, provided that the battery condition is monitored at regular intervals (not to exceed one week). Note that an equalizing charge normally requires that equalizing voltage be applied continuously for 35 to 70 h or longer. (Refer to manufacturer's instructions.)

(1) An equalizing charge should be given if the specific gravity, corrected for temperature and electrolyte level, of an individual cell is more than 10 points (0.010) below the average of all cells at the time of inspection.

(2) An equalizing charge should be given if the average specific gravity, corrected for temperature and electrolyte levels, of all cells drops more than 10 points (0.010) from the average installation value. [Refer to IEEE Std 484-1987 [8], 6.3.1(6).]

4.4.3 An equalizing charge should be given immediately if any cell voltage is below 2.13 V (see Appendixes) at the time of inspection.

4.4.4 Other Equalizing Charge. If not required by 4.4.2(1) or (2) or 4.4.3, an equalizing charge should be given at least once every 18 months. This equalizing charge can be waived for certain batteries based on an analysis of the records of operation and maintenance inspections (Section 8).

4.4.5 Other Abnormalities. Correct any other abnormal conditions noted.

NOTE: See Appendixes for a more detailed discussion of these abnormalities and the urgency of the corrective actions.

4.5 State of Charge. State of charge is normally indicated by specific gravity readings. However, specific gravity readings may not be accurate when the battery is on charge following a discharge or following the addition of water. When cell design permits, specific gravity reading accuracy can be improved by averaging several readings taken at different l vels within a cell. A more accurate indicator of return to full charge is a stabilized charging or float current (see Appendixes).

[3] Numbers in brackets correspond to those of the references listed in Section 3 of this standard.

5. Capacity Test Schedule

The following schedule of capacity tests is used to (1) determine whether the battery meets its specification or the manufacturer's rating, or both; (2) periodically determine whether the performance of the battery, as found, is within acceptable limits; and (3) if required, determine whether the battery as found meets the design requirements of the system to which it is connected.

5.1 Acceptance. An acceptance test of the battery capacity (see 6.4) should be made either at the factory or upon initial installation as determined by the user. The test should meet a specific discharge rate and duration relating to the manufacturer's rating or to the purchase specification's requirements.

NOTE: Batteries may have less than rated capacity when delivered. Unless 100% capacity upon delivery is specified, initial capacity can be as low as 90% of rated. This will rise to rated capacity in normal service after several years of float operation. (See ANSI/IEEE Std 485-1983 [4].)

5.2 Performance

(1) A performance test of the battery capacity (see 6.4) should be made within the first 2 years of service. Initial conditions shall be as described in 6.1, omitting requirements (1) and (2). Results of this test reflect all factors, including maintenance, that determine the battery capability. It is desirable for comparison purposes that the performance tests be similar in duration to the battery acceptance test (see 5.1). If on a performance test the battery does not deliver its expected capacity, the test should be repeated after the requirements of 6.1 (1) and (2) have been completed.

(2) Additional performance tests should be given to each battery at 5 year intervals until it shows signs of degradation as outlined in 5.2 (3).

(3) Annual performance tests of battery capacity should be given to any battery that shows signs of degradation or has reached 85% of the service lif expected for the application. Degradation is indicated when the battery capacity drops more than 10% of rated capacity from its capacity on the previous performance test, or is below 90% of the manufacturer's rating.

(4) When a service test is also being used on a regular basis (see 5.3) it will reflect maintenance practices, so the performance test can be modified to include the requirements of 6.1 (1) and (2). However, when the performance test is used in lieu of a service test, eliminate (1) and (2) of 6.1 so as to provide maintenance factors.

5.3 Service. A service test of the battery capability (see 6.6) may be required by the user to meet a specific application requirement upon completion of the installation. This is a test of the battery's ability as found to satisfy the design requirements (battery duty cycle) of the dc system. This test is performed for Class 1E nuclear power generating station batteries as part of the preoperational and periodic dc system tests described in ANSI/IEEE Std 308-1980 [2]. If the system design changes, sizing (ANSI/IEEE Std 485-1983 [4]) will have to be reviewed, and the service test may have to be repeated.

6. Procedure for Battery Capacity Tests

This procedure describes the recommended practice of capacity testing by discharging the battery. For nuclear power stations use of Class 1E batteries, also refer to ANSI/IEEE Std 323-1983 [3]. All testing should follow the safety requirements listed in 4.2.

6.1 Initial Conditions. The following list gives the initial requirements for all battery capacity tests. For performance (see 5.2) and service (see 5.3) tests when the results should reflect maintenance practices, omit requirements (1) and (2) below. The most stringent performance and service test conditions will be just prior to the scheduled equalizing charge (see 4.4.4).

(1) Verify that the battery has had an equalizing charge completed more than 3 days and less than 7 days prior to the start of the test.

(2) Check all battery connections and make sure that all connectors are clean, tight, and free of corrosion.

(3) Read and record the specific gravity and float voltage of ach cell just prior to the test.

(4) Read and record the temperature of the battery electrolyte for an average temperature (suggested every sixth cell).

(5) Read and record the battery terminal float voltage.

(6) Disconnect the charger from the battery.

(7) Take adequate precautions (such as isolating the battery to be tested from other batteries and critical loads) to ensure that a failure will not jeopardize other systems or equipment.

6.2 Test Length. The recommended procedure is to make a capacity test for approximately the same length of time as the critical period for which the battery is sized. See 6.6 for test length of the service test.

6.3 Test Discharge Rate. The discharge rate depends upon the type of test selected. For the acceptance test or performance test the discharge rate should be a constant current load equal to the manufacturer's rating of the battery for the selected test length. See 6.6 for the test discharge rate of the service test.

Note that the test discharge current is equal to the rated discharge current divided by *K*, where *K* is the discharge current correction factor for the initial electrolyte temperature. See Table 1.

6.4 Acceptance and Performance Tests. Set up a load with an ammeter and a voltmeter with the provisions that the load be varied to maintain a constant current discharge equal to the rating of the battery at the selected rate (see 6.3).

(1) Connect the load to the battery, start the timing, and continue to maintain the selected discharge rate.

(2) Maintain the discharge rate until the battery terminal voltage decreases to a value equal to the specified average voltage per cell (usually 1.75 V) times the number of cells.

(3) Read and record individual cell voltages and the battery terminal voltage. The readings should be taken while the load is applied at the beginning and the completion of the test and at specified intervals. There should be a minimum of three sets of readings.

NOTE: Individual cell voltage readings should be taken between respective posts of like polarity of adjacent cells, so as to include the voltage drop of the intercell connectors.

Table 1
Discharge Current Correction Factor *K* for Temperature

Initial Temperature (°C)	(°F)	Factor *K*
−3.9	25	1.520
−1.1	30	1.430
1.7	35	1.350
4.4	40	1.300
7.2	45	1.250
10.0	50	1.190
12.8	55	1.150
15.6	60	1.110
18.3	65	1.080
18.9	66	1.072
19.4	67	1.064
20.0	68	1.056
20.6	69	1.048
21.1	70	1.040
21.7	71	1.034
22.2	72	1.029
22.8	73	1.023
23.4	74	1.017
23.9	75	1.011
24.5	76	1.006
25.0	77	1.000
25.6	78	0.994
26.1	79	0.987
26.7	80	0.980
27.2	81	0.976
27.8	82	0.972
28.3	83	0.968
28.9	84	0.964
29.4	85	0.960
30.0	86	0.956
30.6	87	0.952
31.1	88	0.948
31.6	89	0.944
32.2	90	0.940
35.0	95	0.930
37.8	100	0.910
40.6	105	0.890
43.3	110	0.880
46.1	115	0.870
48.9	120	0.860
51.7	125	0.850

NOTE: This table is based on nominal 1.210 specific gravity cells. For cells with other specific gravities refer to the manufacturer. The manufacturers recommend battery testing be performed between 65 °F and 90 °F.

(4) If an individual cell is approaching reversal of its polarity (plus 1 V or less) but the terminal voltage has not yet reached its test limit, the test should be continued with a jumper across the weak cell. Complete the jumper connection away from the cell to avoid arcing near the cell. The new minimum terminal voltage should be determined based on the remaining cells [see 6.4 (2)].

NOTE: The possibility of a weak cell(s) should be anticipated and preparations made for jumpering the weak cell with minimum hazard to personnel.

(5) Observe the battery for intercell connector heating.

(6) At the conclusion of the test, determine the battery capacity according to the procedure outlined in 6.5.

6.5 Determining Battery Capacity. For an acceptance or performance test, use the following equation to determine the battery capacity:

$$\% \text{ capacity at } 25\,^\circ\text{C } (77\,^\circ\text{F}) = \frac{T_a}{T_s} \cdot 100$$

where

T_a = actual time of test to specified terminal voltage [see 6.4(2)]

T_s = rated time to specified terminal voltage

6.6 Service Test. A service test is a special battery capacity test which may be required to determine if the battery will meet the design requirements (battery duty cycle) of the dc system (see 5.3). The system designer should establish the test procedure and acceptance criteria prior to the test. Recommended procedure for the test is:

(1) The initial conditions shall be as identified in 6.1 [omit items (1) and (2)].

(2) The discharge rate and test length should correspond as closely as is practical to the design requirements (battery duty cycle) of the dc system.

(3) If the battery does not meet the design requirements of the dc system, review its rating to see if it is properly sized, equalize the battery, and, if necessary, inspect the battery as discussed in 4.3, take necessary corrective actions, and repeat service test. A battery performance test (see 5.2) may also be required to determine whether the problem is the battery or the application.

6.7 Restoration. Disconnect all test apparatus. Recharge, equalize if necessary, and return to normal service.

7. Battery Replacement Criteria

The recommended practice is to r place the battery if its capacity as determined in 6.5 is below 80 percent of the manufacturer's rating. The timing of the replacement is a function of the sizing criteria utilized and the capacity margin available, compared to the load requirements. Whenever replacement is required, the recommended maximum time for replacement is 1 year. A capacity of 80 percent shows that the battery rate of deterioration is increasing even if there is ample capacity to meet the load requirements. Other factors, such as unsatisfactory battery service test results (see 6.6), require battery replacement unless a satisfactory service test can be obtained following corrective actions.

Physical characteristics, such as plate condition together with age, are often determinants for complete battery or individual cell replacements. Reversal of a cell as described in 6.4(4) is also a good indicator for further investigation into the need for individual cell replacement. Replacement cells, if used, should be compatible with existing cells and should be tested prior to installation. Replacement cells are not usually recommended as the battery nears its end of life.

Failure to hold a charge, as shown by cell voltage and specific gravity readings, is a good indicator for further investigation into the need for replacement.

8. Records

Data obtained from inspections and corrective actions are important to the operation and life of the batteries. Data such as indicated in 4.3 should be recorded at the time of installation and as specified during each inspection. Data records should also contain reports on corrective actions (see 4.4) and on capacity and other tests indicating the discharge rates, their duration, and results.

At nuclear stations, records of Class 1E batteries shall include a written test procedure and documentation adequate to meet the requirements of ANSI/IEEE Std 308-1980[2], ANSI/IEEE Std 494-1974[5], and ANSI/IEEE Std 535-1986[6].

It is recommended that forms be prepared to record all data in an orderly fashion and in such a way that comparison with past data is convenient. For a suggested format see ANSI/IEEE Std 323-1983[3], Section 8. A meaningful comparison will require that all data be converted to a standard base in accordance with the manufacturer's recommendations.

Appendixes

(These Appendixes are not a part of ANSI/IEEE Std 450-1987, Recommended Practice for Maintenance, Testing, and Replacement of Large Lead Storage Batteries for Generating Stations and Substations, but are included for information only.)

The corrective actions listed in 4.4 are meant to provide optimum life of the battery. They in themselves will not guarantee that the battery is completely charged at any given time. These appendixes will provide some technical background for the necessary actions and their timing and provide another more accurate means for determining the state of charge of a battery which has a specific gravity gradient.

Appendix A

Specific Gravity

A1. Effect of Charging

During the recharge of a battery, high-specific-gravity sulfuric acid is generated. This acid will sink toward the bottom of the cell, resulting in a specific gravity gradient which produces an incorrect low reading at the top of the cell. Therefore it is normal for the state of charge as indicated by the specific gravity at the top of the cell to lag behind that indicated by the ampere-hours of recharge current. Charging voltage limits do not ordinarily allow enough recharge current to provide mixing action. Therefore this gradient may persist until corrected by diffusion.

A2. Effect of Temperature

Specific gravity readings are based on a temperature of 77 °F (25 °C). The readings should be corrected for the actual electrolyte temperature and level (see A3). For each 3 °F (1.67 °C) above 77 °F add 1 point (0.001) to the reading. Subtract 1 point for each 3 °F below 77 °F.

A3. Effect of Electrolyte Level

The specific gravity of the lectrolyte in a cell will increase with a loss of water due to electrolysis or evaporation. When specific gravity r adings are being taken, the electrolyte levels should also be measured and recorded. The battery manufacturer will provide a gravity correction factor for the particular cells involved.

The apparent electrolyte level depends on the charging rate because gas generated during charging causes an apparent expansion of the electrolyte. If the electrolyte is at or near the high-level mark at float voltage, it may rise above that mark on charge. This condition is not objectionable. It does dictate, however, that electrolyte level readings should be made only after the battery has been at float voltage for at least 72 h.

A4. Effect of Water Additions

When water is added to a cell, it tends to float on top of the electrolyte because its specific gravity is 1.000 in comparison to 1.210 nominal for the electrolyte in most batteries. If the cells are in a normal float charge condition, there is very little mixing of the electrolyte due to gassing. In certain cell types it may take 6 to 8 weeks or longer for complete mixing to occur. The specific gravity should be read before adding water, or the battery should be given an equalizing charge after the water has been added. The battery should be back on normal float voltage for 72 h before the specific gravity is measured after an equalizing charge.

Appendix B

Determining the State of Charge When a Specific Gravity Gradient Exists

When the cell is designed so that specific gravity readings can be made at the top, middle, and bottom of the cell, the average of these three readings will accurately relate the state of charge to the full-charge specific gravity specified by the manufacturer.

The pattern of charging current delivered by a conventional *voltage-regulated* charger after a discharge provides another method for determining the state of charge. As the cells approach full charge, the battery voltage rises to approach the charger output voltage, and the charging

current decreases. When the charging current has stabilized at the charging voltage, *the battery is charged*, even though specific gravities have not stabilized.

If the charging voltage has been set at a value higher than normal float voltage (so as to reduce charging time), it is normal practice to reduce the charging voltage to a float value after the charging current stabilizes. The float current will soon stabilize, even though the top level specific gravity readings continue to increase.

NOTE: Refer to the manufacturer's instructions for time periods to maintain charging voltages after current stabilization.

Appendix C
Float Voltage

C1. Low-Voltage Cells

Cell voltage is not, by itself, an indication of the state of charge of the battery. Prolonged operation of cells below 2.13 V can reduce the life expectancy of cells. If normal life is to be obtained from these cells, they should be given an equalizing charge.

NOTE: A cell voltage of 2.07 V or below under float conditions and not caused by elevated temperature of the cell indicates internal cell problems and may require cell replacement.

C2. High-Voltage Cells

There is no detrimental effect associated with a cell that has a float voltage higher than the average of the other cells in the battery except for the extreme case where the cell potential equals or exceeds the gassing potential (2.38 V at 25 °C). If an equalizing charge is given to the battery, the float voltage of the other cells will be increased, and the float current will be decreased. This decrease will lower the voltage of the high cell.

NOTE: The condition can also exist when a few new cells are added to an old battery as replacements.

C3. Effect of Temperature

As the temperature of th electrolyte incr ases, resistivity decreases and the charging current increases in order to maintain a constant cell voltage. Therefore, cells in a battery at a higher temperature than others will require higher current. However, as the cells are in series, the current is determined by the charger voltage and the average temperature of the battery. The voltage of the warmer cells will be lower than the average.

If a warmer cell is below 2.13 V, its temperature-corrected voltage can be determined by adding 0.003 V for each degree Fahrenheit (0.005 V/°C) that the cell temperature is above the average temperature of the other cells. If the cell voltage is less than 2.13 V after being corrected for the effects of temperature, an equalizing charge is required. An effort should be made to eliminate the cause of the temperature differential. (Refer to Appendixes C1 and D3.)

When all cells are at some higher temperature, the charging current under normal float conditions will automatically increase to hold the required float voltage. However, individual cell voltages will not be affected and no correction for temperature will be necessary.

Appendix D
Urgency of Corrective Actions

D1. Adding Water

For capacity, the addition of water is not urgent unless the tops of the plates are in danger of being exposed. However, for safety, if flame-arresting vents are provided, water should be added before the electrolyte level reaches the bottom of the funnel stem. Electrolyte levels above the high level line will not affect safety or capacity unless the cell reaches an electrolyte overflow condition.

If the level of electrolyte has dropped low enough to expose plates, check gravity where possible and then add water to at least the low level line. If visual inspection shows no evidence of leakage, then equalize and test in accordance with the manufacturer's recommendation.

D2. Connection Resistance

It is good practice to read and record intercell and terminal connection d tail resistances as a baseline upon installation as recommended by IEEE Std 484-1987[8]. It is very important that

the procedure be consistent so as to detect upward changes that could be caused by corrosion or loose connections. Increased resistance is a cause for concern and may require corrective action.

Normal installation resistances vary greatly as a function of the size of the installation, for example from less than 10 $\mu\Omega$ for a large battery to as much as 100 $\mu\Omega$ for a smaller battery. Methods for taking these readings include use of digital low resistance ohmmeters or measurement of mV drop during capacity testing. The manufacturer should be contacted for the expected values. It is customary to use either a 20% change in the previously established baseline value or a value exceeding the manufacturer's recommended limit as a criteria for initiation of corrective action prior to the next inspection. The timing of corrective actions should be determined by an analysis of the effects of the increased resistance.

D3. Cell Temperature

Large cell-temperature deviations are usually caused by shorting conditions, which are also evident by the cell voltage. This is cause for immediate cell replacement. All other temperature deviations are usually caused by outside conditions that are part of the installation [see IEEE Std 484-1987[8], 5.1.1(5)]. While operation at elevated temperatures will reduce life expectancy, it will not adversely affect capacity.

D4. Equalizing Charge

In general, the need for initiating an equalizing charge is not critical. However, a deviation in the specific gravity of more than 10 points (0.010) is a cause for concern and should be analyzed for its effect on battery capability. The need for an equalizing charge and any other corrective action necessary is directly proportional to the deviation. When the average gravity of the battery drops more than 10 points (0.010) from the acceptance test value, the charge should be as high as permissible (within dc system design limits).

When an individual cell voltage corrected for temperature is below 2.13 V, corrective action should be initiated immediately. It can be accomplished by providing an equalizing charge to the entire battery. However, it is often more convenient to apply the equalizing charge to the individual cell. This may be done during normal float operation of the battery.

Appendix E

Alternative Practices for Non-Class 1E Nuclear Applications

As outlined in Section 4.3 of this recommended practice, periodic inspections and the subsequent corrective actions are intended to provide a properly maintained battery that will meet its performance requirements. The performance and service tests outlined in Sections 5.2 and 5.3 can be used to demonstrate the adequacy of the maintenance practices. Each of these recommended practices of inspections and tests should be used as best suited for the particular needs of the application. It is the user's responsibility to format his maintenance, inspection and testing program to optimize the benefits available.

All sections of this recommended practice need not apply in all situations. For example, on some small battery installations (such as substations), some users perform a short term high rate discharge test which can be accomplished without removing the battery from service. Tests of this nature can provide a useful indication of the battery's capability to perform its design function and will reduce the need for some other inspections and tests.